1 up

NASA TECHNICAL TRANSLATION NASA TT F-15,268

MEASUREMENT OF THE STROKE VOLUME BY AN INTEGRAL RHEOGRAM OF THE HUMAN BODY

M. I. Tishchenko

(NASA-TT-F-15268) MEASUREMENT OF THE STROKE VOLUME BY AN INTEGRAL RHEOGRAM OF THE HUMAN BODY (Techtran Corp.) ~~16~~ 17 p HC

N74-14833

Unclas

G3/04 27502

Translation of "Izmereniye Udarnogo Ob"ema Krovi po Integral'noy Reogramme Tela Cheloveka," "Fiziologicheskiy Zhurnal SSSR," Vol. 59, No. 8, August 1973, pp. 1216-1224

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 JANUARY 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,268	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle MEASUREMENT OF THE STROKE VOLUME BY AN INTEGRAL RHEOGRAM OF THE HUMAN BODY		5. Report Date January 1974
		6. Performing Organization Code
7. Author(s) M. I. Tishchenko		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Techtran Corporation P.O. Box 729, Glen Burnie, Md. 21061		11. Contract or Grant No. NASw-2485
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Izmereniye Udarnogo Ob"ema Krovi po Integral'noy Reogramme Tela Cheloveka," "Fiziologicheskiy Zhurnal SSSR," Vol. 59, No. 8, August 1973, pp. 1216-1224.

16. Abstract

Two electrically short-circuited electrodes are applied to the distal areas of the forearm and two electrodes connected in the same fashion are applied to the distal areas of the shins. When the measuring arm of a bridge rheograph is connected between the paired electrodes of the upper and lower extremities, a curve is recorded which is the integral rheogram of the body. This curve reflects the total pulse variation of the electrical resistance of the vessels that are located between the electrodes and is caused primarily by the pulse variations in the volume of the large longitudinal arterial trunks. A formula was worked out to calculate the stroke volume of the left ventricle according to the anacrotic part of the integral rheogram. Data were obtained that are in agreement with the acetylene method, the method of thermodilution and the direct Fick method. The possibility of measuring the stroke volume for each cardiac contraction was established.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages ~~15~~ 17

MEASUREMENT OF THE STROKE VOLUME BY AN INTEGRAL RHEOGRAM OF THE HUMAN BODY

M. I. Tishchenko[1]

Clinical medicine, particularly thoracic surgery, now has at its disposal very accurate methods for measuring the minute volume of circulation, such as the direct Fick method and the method of thermodilution [2, 12]. Due to the necessity of catheterization of the heart, these methods are only used on the basis of strict indications for certain groups of patients. However, they cannot be used to study circulation in healthy individuals and for large contingents of patients. Moreover, as is the case for the more widely used method of dye dilution, these methods have the disadvantage that they provide only an idea of the average value of the stroke volume of the blood over a rather long time interval. The dynamics of the changes in stroke volume from one cardiac contraction to the next are lost. /1216*

Sphygmographic methods are completely safe, but the accuracy of the data which are obtained raise doubts in many instances. These methods also do not allow determination of the stroke volume for each cardiac contraction due to the use of the same value for the pulse pressure for various cycles.

The ideal method would be one in which it would be possible to use some single form of external phenomenon of cardiac activity to measure reliably the stroke volume for each contraction, without affecting the measured parameter, thereby one which would be completely safe and suitable for frequent and repeated application. From this standpoint, considerable attention has been attracted by successful attempts at determining the stroke volume on the basis of segmental rheograms of the chest [3-6, 16, 17, 19, 22, 24]. However,

---

[1]Laboratory of Clinical Physiology (Head: Ye. B. Babsky), Institute of Normal and Pathological Physiology, Academy of Medical Sciences USSR, Moscow.

*Numbers in the margin indicate pagination in the foreign text.

thoracic rheography has certain shortcomings as well (need to hold the breath, arbitrary extrapolation of curves, use of conditional (equivalent) values for the basic resistance of the necessity for recording additional processes).

For a long time, researchers have been interested in determining the stroke volume on the basis of the ballistocardiogram [23]. The basis of this is a carefully worked out theory of the method [23], from which follows the theoretical possibility of determining the stroke volume. We know [1, 8, 9, 23] that only one version of this method -- ultralow-frequency ballistocardiography -- can be viewed as a potentially suitable method for this purpose and only under the condition of strict adherence to all of the theoretical requirements. Our attempts at determining the stroke volume in healthy individuals using an instrument that satisfies the theoretical requirements [8, 9] showed that the use of the most reliable formula of Clench [23] for these calculations gives results that are reduced and possess poor reproducibility. The replacement in this formula of the amplitude of the M wave by the total sum of amplitudes of all waves in the systolic part of the ultralow-frequency ballistocardiogram (2I + M) noticeably improves the reliability of the determination of the stroke volume and makes it possible to obtain data which are comparable with those obtained by the acetylene and dye dilution methods. The technical complexity and critical nature of many of the parameters of the instrument, the need to hold the breath, the indirect reproducibility of the result and the fixed nature of the instrument design do not allow us to view the ultralow-frequency ballistocardiograph as a method which has very promising prospects. However, from the plethysmographic theory of ultralow-frequency ballistocardiography and the satisfactory results that have been obtained over the total sum of the amplitudes of the waves for the stroke volume, we can assume that the distribution of the stroke volume over the main longitudinal arterial trunks is most completely characterized by the general sum (integral) of the ballistic forces during the cardiac cycle, independent of the direction of movement of the platform of the ballistocardiograph. Using this as a basis, along the lengthwise ultralow-frequency ballistocardiogram we can plot the theoretical pulse plethysmogram (Figure 1, 2) for the entire body. The theoretical pulse plethysmograms plotted on the basis of the ultralow-frequency ballistocardiograms of various individuals constitute multiphase curves which have the shape /1217 and appearance of an arterial volume sphygmogram. The actual existence of such a pulse plethysmogram for the entire human body can be demonstrated in the case when it can be experimentally recorded by some other method. On the basis of the fact that the formation of the ultralow-frequency ballistocardiogram and consequently the theoretical pulse plethysmogram involves an important role being played not only by the volume changes in the aorta but also the large arteries of the extremities, we made an attempt to obtain the total pulse plethysmogram of the body by another method -- the rheographic method, by applying electrodes to the parts of the body located farthest apart. The goal in this effort was to obtain as complete a picture as possible of the cyclic volume changes in all of the vessels along the lengthwise axis of the body. In addition to the concepts based on the theory of ultralow-frequency ballistocardiography, the choice of the location and connection of the electrodes was governed by an effort to reduce the errors in measurement of the basic (interelectrode) resistance. We know that the human body is a volume conductor of the second type with stratified (inhomogeneous) conductivity [7, 13, 15, 18, 20, 21]. Electrical conductivity is determined primarily by the blood plasma, which is in the largest vessels. Therefore, the application of electrodes according to a geometric projection of a given organ or a given vessel is not a /1218 guarantee that the volume changes in precisely this organ are being recorded, and the interelectrode resistance is governed by its electrical conductivity. This is explained by the fact that in a segmental application of the electrodes (in any of its forms) to some degree or other there is a "leakage" of the loops of the measuring current into other regions, primarily vessels of the largest diameter, causing significant distortions of the measured values. By deliberately connecting the electrodes to diametrically opposite parts of the body and passing the measuring current successively through all the vessels located between the electrodes, it is possible to reduce (or in any case stabilize) the errors in measurement of the actual value of the basic resistance. The cyclically repeating curve thus obtained, completely corresponding to the theoretical pulse plethysmogram of these same individuals, was the basis for finding methods of calculating the stroke volume of the blood on the basis of this curve with the same theoretical assumptions as in ultralow-frequency ballistocardiograms.

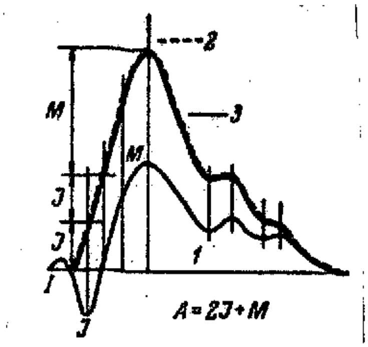

Figure 1. Ultralow-Frequency Ballistocardiogram (1) of a Healthy Individual, Theoretical Pulse Plethysmogram of the Entire Body Plotted on it (2) and Integral Rheogram of the Body (3) of the Same Individual. A, Total sum of amplitudes of systolic waves of ultralow-frequency ballistocardiogram.

Method

Two electrodes, electrically short-circuited, are applied to the distal portions of the volar surface of the forearms and two electrodes connected in the same fashion are attached to the distal portions of the shins (Figure 2). Equal success was obtained by using flat electrodes (including electrocardiographic ones) made of different materials (lead, silvered brass and so forth) with a total area of 100-1,120 cm^2. Between the electrodes and the skin, we applied cloth coverings (pieces of flannel, totally covering the electrode), moistened with alkaline electrolyte, which considerably stabilized the intermediate resistance. The electrodes were fastened to the extremities by rubber straps.

The measuring arm of an RG1-01 bridge rheograph was connected between the paired electrodes of the upper and lower extremities (Figure 2). After balancing the bridge rheograph on the basis of the active (R_b) and reactive (C_b) components of the impedance, a signal proportional to the cyclic changes in the electrical resistance (ΔR in Figure 2) was supplied to the polycardiograph and recorded by the latter in the form of a curve that reflected the cyclic pulse changes in the volume of the vessels in a continuous chain: arms-trunk-legs.

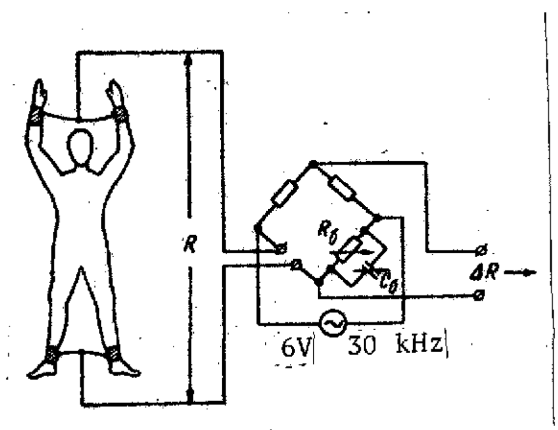

Figure 2. Diagram of the Arrangement and Connection of Electrodes for Recording the Integral Rheogram of the Body. Explanation in the text.

The choice of the type of rheograph was governed by the fact that this model has a bridge circuit that makes it possible, following preliminary calibration of the balancing elements on the basis of the active component (switch "R-coarse" and potentiometer "R-fine") to measure the basic resistance (R in Figure 2) with sufficient accuracy (0.5-1 ohm), and also allows sufficiently accurate compensation of the capacitance component, operating at a frequency of 30 kHz, which is less affected by changes caused by variations in the linear velocity of the blood flow [7]. However, the RG1-01 rheograph does not completely satisfy the requirements of accurate measurement. This is due primarily to the unsatisfactory amplitude characteristic of the instrument caused by the double half-wave detector. A special study revealed that in order to have undistorted reproduction of the rheogram and calibration pulse (0.1 ohm) it is necessary as a minimum, after zeroing the bridge, to apply an artificial imbalance to the measuring arm. The degree of imbalance is critical and must be between 0.7 and 1.7% (1.25% on the average) of the value of the basic resistance R of a given individual. In addition to the calibration of the bridge, the introduction of such an imbalance (by means of an additional switch with resistances from 1 to 4 ohms in steps of 0.5 ohm) makes it possible to measure the amplitude of the rheogram with an error of no more than 5% over the entire range of values for the basic resistance encountered in practice (from 100 to 400 ohms, usually an average of 200-250 ohms). Much better results (improvement of the linearity of the amplitude characteristic, expansion of the dynamic range) are provided by adding to the RG1-01 system an annular phase-sensitive detector, but this calls for extensive rebuilding of the instrument.

Using the arrangement and connection of the electrodes shown in Figure 2, /1219 a curve was plotted (Figure 1, 3) for the total change in the electrical resistance produced by the pulse variations in the volume of all the vessels along the lengthwise axis of the body, and therefore the integral rheogram of the body, as we call it. Its recording does not require holding the breath. In conjunction with the significant distance of the electrodes from the lungs and the high amplitude of the integral rheogram of the body, quiet breathing appears in the recording in the form of insignificant variations in the zero line. The basic harmonics of the systolic part of the integral rheogram of the body lie within the 2-20 Hz range. Therefore, the time constant of the output circuit of the rheograph can be decreased to 0.5 seconds, without affecting the accuracy of reproduction of the systolic part of the curve. The latter makes it possible to record the integral rheogram with forced breathing and with any other type of artificial ventilation of the lungs, which expands the possibility of the use of the method.

The integral rheogram of the human body is a monophasic curve (Figure 1, 3) with a shape similar to the volume arteriosphygmogram. In healthy individuals, one can clearly see the anacrotic rise and the catacrotic decline with an incisura, the dicrotic wave and the secondary oscillations. When we compare the integral rheogram of the body with the polycardiographic data [8, 9] and with the data from catheterization of the pulmonary artery and aorta in man (Figure 3), we can see a precise coincidence of the beginning of the anacrotic rise with the beginning of expulsion of blood from the left ventricle. The highest point of anacrotic rise coincides with the top of the M wave in the ultralow-frequency ballistocardiogram and is close to the moment of the completion of the period of expulsion of the left ventricle, although it precedes it in healthy persons by 0.02-0.03 second. The anacrotic rise is frequently preceded by variations of small amplitude (of the presphygmic wave type), coinciding in duration with the period of stress on the left ventricle.

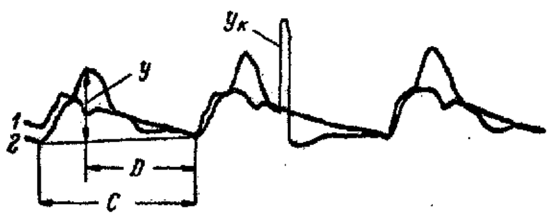

Figure 3. Curve of Pulse Variations in the Pressure in the Aorta of an Individual (1) and the Integral Rheogram of the Body (2) Recorded Simultaneously.
y, Amplitude of the anacrot of the integral rheogram of the body; y_k, Amplitude of calibration (0.1 ohm); C, Duration of cardiac cycle; D, Duration of the catacrotic part of the integral rheogram of the body.

A harmonic analysis has revealed that the frequency spectrum of the integral rheogram of the body corresponds in all respects to the one for the theoretical pulse plethysmogram and the ultralow-frequency ballistocardiogram of the same person, which also confirms the common nature of their origin. The spectrum of the integral rheogram of the body is poorer in high (20th and over) harmonics, than the central pulse, but is richer in average frequency harmonics (10-15) than the peripheral pulse (femoral artery). It may be assumed that the integral rheogram of the body, like the ultralow-frequency ballistocardiogram, reflects both the central peripheral components of the pulse redistribution of the stroke volume of blood. Obviously, we can view the integral rheogram of the body as a volume sphygmogram of the arterial compression chamber as a whole, reflecting the real pulse redistribution of the blood volume during the cardiac cycle. The latter idea has been a prerequisite for the study of the theoretical possibility of calculating the stroke volume of the left ventricle.

As a basis for calculating the stroke volume of blood (Q) we selected a formula which is used in segmentary rheography for calculating the volume changes in a cylindrical conductor [5, 19, 21, 62, 24]. However the shape of /1220 the current-carrying medium of a part of the body and even more so of the body as a whole differs considerably from cylindrical [15, 18, 20]. We have insufficient theoretical data to correct these differences. Therefore, in the denominator (differences in the shape of the current-carrying media from strictly geometric influence primarily the basic resistance) of the formula we conditionally introduced a correction factor (K); we performed an experimental study to determine the limits of its value. In 12 healthy individuals the Q value was determined by the acetylene method and the integral rheograms of the body were recorded simultaneously. We used these to determine the values of all of the parameters that are found on the right-hand side of the formula except for K. Each equation that was obtained was solved in partial values with respect to K. For all of the subjects, we obtained the distinctive values of K that lie over a wide range (from 0.27 to 0.44). We could not use the average values of K since the mean square error in the calculation of the stroke volume is then too large -- 21%. However, it was determined at the same time that for all of the subjects the individual values of K are distinctly linked to the value of the basic resistance R, to wit: $K \cdot R = 100$. Expressing K through this complete inverse dependence (coefficient of rank correlation -- 0.985) in the form $K = 100/R$ and substituting it in the original equation, it was possible to obtain the universal (automatically calculating the individual values of K) formula for calculating the stroke volume on the basis of the integral rheogram of the body as follows:

$$Q_{(cm^3)} = \rho\,\frac{\Delta R \cdot L^2}{K \cdot R^2} \cdot \frac{C}{D} = \frac{150 \cdot y/y_k \cdot 0.1 L^2}{100 \cdot R} \cdot \frac{C}{D},$$

where R (ohms) is the basic resistance measured by balancing the rheograph bridge: $\Delta R = y/yk \cdot 0.1$ (ohm) is the pulse variation in the resistance (y is the amplitude of the anacrot of the integral rheogram of the body, y_k is the amplitude of calibration, 0.1 ohm) (see Figure 3); ρ is the specific resistance of the blood, which our data give as 150 ohms per cm; L is the distance between the electrodes according to the projection of the basic arterial trunks (cm); C is the length of the cardiac cycle, and D is the duration of the catacrotic portion of the integral rheogram of the body in the same cycle (Figure 3).

Further investigation revealed the possibility of replacement of L in this formula by a value expressed by the increase -- l (cm). The distance between the electrodes, as was shown by a study of 95 individuals, is expressed by the increase with good accuracy, which does away with the need for direct measurement of L by summation of segments. However, this dependence is reliably different for men and women and has the form: $L_{men} = 1.32\ l$ and $L_{women} = 1.25\ l$.

In order to study the suitability of the formula obtained, we performed a series of comparisons of the values for the minute volume of the blood obtained on the basis of the integral rheogram of the body and simultaneously on the basis of controlled methods.[2]

In healthy persons, the comparison was performed with the acetylene method of Grol'man (see the table). To expand the range of compared values, the study was performed under conditions of basal metabolism (lying down and sitting up) and outside the conditions of basal metabolism [11]. In order to match the measured values, recording of the integral rheogram of the body was performed before breathing acetylene and immediately afterward. The final value of the minute volume was calculated as the average value before and after breathing acetylene.

---

[2] G. P. Zvonarev, L. N. Danilov and A. L. Aleksandrov took part in comparing the data from the integral rheogram of the body with the control methods.

The control methods we used (acetylene, thermodilution and the direct Fick method) constitute methods of measurement of the minute volume of the blood circulation. Therefore, in order to compare the data in one dimension of the values of the basis of the integral rheogram of the body, we also calculated the minute volume. For this purpose, using the integral rheogram of the body, the measurement of the parameters y, C and D was conducted sequentially in all /1221 the complexes which form the total respiratory cycle. The periodic nature of the respiratory changes in the amplitude of the integral rheogram of the body are clearly visible from the recording and the determination of the duration of the respiratory cycle poses no difficulties. The starting points of the anacrotic rise in all of the combined complexes of the integral rheogram of the body per respiratory cycle (from 3 to 7, usually 5 -- as a function of the ratio of the frequencies of the pulse and the respiration) were successively joined by straight lines, and we measured the values of y and C/D in each of them (see Figure 3). To calculate the average value of the stroke volume we used the average values of these parameters and the calibration pulse (y_k) which is located on the recording as close as possible to the given respiratory cycle (or better -- within it). The calibration pulse must be located in the diastolic portion of the integral rheogram of the body (Figure 3). To determine the minute volume in calculating the pulse frequency we use the average value C.

A comparison of the values for the minute volume as obtained by the acetylene method and calculated in this fashion from the integral rheogram of the body showed their statistically reliable comparability (see the table). In recording the integral rheogram following breathing of acetylene it was found that in the overwhelming majority of subjects there is a noticeable (10-15%) decrease in the minute volume. Recovery takes place after 5 or 10 minutes and always corresponds to the moment when the subject fails to detect the odor of acetylene in the expired air. It is probable that this decrease is a regular reflex reaction to the breathing of acetylene -- a gas which has an odor. This obviously can explain to a large extent the decrease in the minute volume values when the acetylene method is used, as has been observed by many investigators.

STATISTICAL CHARACTERISTICS OF A COMPARISON OF THE VALUES OF THE MINUTE VOLUME OF THE BLOOD CIRCULATION CALCULATED ON THE BASIS OF THE INTEGRAL RHEOGRAM OF THE BODY WITH DATA OBTAINED BY THE ACETYLENE METHOD, THE THERMODILUTION METHOD AND THE DIRECT FICK METHOD

Control method	Number of comparisons and contingents of subjects	Range of values of the minute volume (l)	Coefficient of correlation (r), its error (m), student criterion (t), reliable probability (p) and coefficient of linear regression (R)	Mean square value of deviation of compared values (σ) (%)
Acetylene method	31 healthy persons.	3.2-8.0	$r = 0.84$ $m = 0.15$ $t = 8.4$ $p > 99.9\%$ $R = 0.8$	13
Thermodilution method	25 patients with various diseases of the lungs.	2.8-10.8	$r = 0.95$ $m = 0.06$ $t = 14.6$ $p > 99.9\%$ $R = 0.8$	12
Direct Fick method	28 patients with various diseases of the lungs and mitral defects of the heart.	2.2-15.5	$r = 0.99$ $m = 0.03$ $t = 39$ $p > 99.9\%$ $R = 0.95$	7

The obtaining of the data compared with the acetylene method formed the basis for further study of the reliability of the integral rheogram of the body. The most important parameter in any measurement method is the reproducibility -- the mean square value of random error. To determine this parameter of the integral rheogram of the body, we used as a control the method of thermodilution /1222 in the modification of L. N. Danilov [2, 12]. Possessing good accuracy for determination of absolute values of the minute volume, this method (in which there is no cumulation of the indicator) makes it possible to carry out many repeated measurements in a given individual; in other words, it is most suitable for evaluating the reproducibility of the method under study. When we compare the data obtained in lung patients (see the table) by the method of thermodilution and by simultaneously recorded integral rheograms of the body, we obtain a good comparability of the values for the minute volume. It was also found that the reproducibility of the integral rheogram is about 5% (the reproducibility of thermodilution in these same studies was 7%). Reproducibility, as we know, is a measure of the resolution of the measurements. Such a high resolution of the integral rheogram of the body indicates that this method is suitable for measuring the stroke volume of blood for each cardiac contraction and not only for calculating the average values.

An analysis of the equations of linear regression, derived on the basis of a comparison with the acetylene method and the method of thermodilution, showed that the calculation based on the integral rheogram of the body contains a slight (-5%) systematic error (initial displacement of calculation). Taking this systematic error into account, and combining all the constant coefficients into one, the improved formula for calculating the stroke volume on the basis of the integral rheogram of the body will have the form

for men:

$$Q_{(cm^3)} = 0.275 \frac{y/y_k \cdot l^2}{R} \cdot \frac{C}{D}$$

for women:

$$Q_{(cm^3)} = 0.247 \frac{y/y_k \cdot l^2}{R} \cdot \frac{C}{D}$$

(symbols as before, l = growth (cm)).

A comparison of the data with a strictly single-moment (immediately after puncture of the femoral artery) determination on the integral rheogram of the body using the latter formula and the direct Fick method showed a high degree of correspondence between the results obtained (see the table). Calculation of the stroke and minute volumes by this formula in patients with different diseases of the lungs and mitral defects of the heart gives data which completely correspond to the ones obtained by the direct Fick method. The relationship between the results obtained can be viewed as totally functional.

It is particularly significant that in repeated studies of the same patients strict correspondance was obtained and there was a parallel nature in the changes in the indices on the basis of the integral rheogram of the body and according to Fick. It must be pointed out that the latter comparison was /1223 carried out over a rather wide range of values of the minute volume (2.2-15.5 liters), pulse frequency (60-143/minute) and age of subjects (18-63 years). In three cases there was fibrillar arrhythmia, and good agreement of data was obtained (average value for Q on the integral rheogram of the body was then calculated not for one respiratory cycle but for 15-20 seconds).

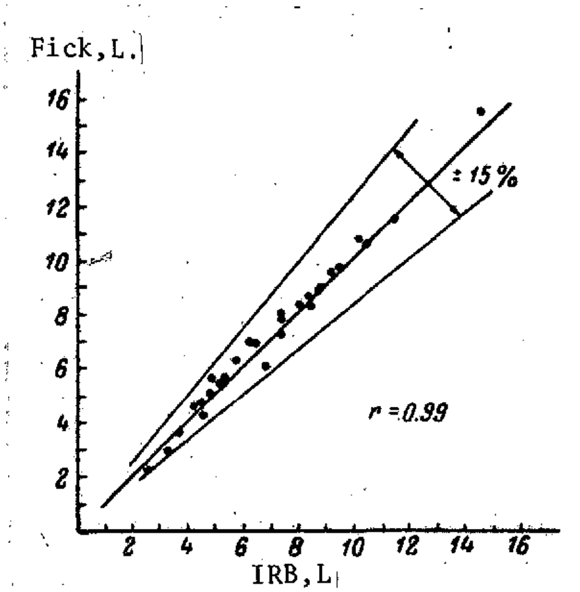

Figure 4. Comparison of the Results of Simultaneous Measurement of the Minute Volume of the Blood Circulation by the Direct Fick Method (and the Integral Rheogram of the Body) (IRB).
r, Correlation coefficient.

This study makes it possible to assume in general that the method of integral rheography allows determination of stroke and minute volumes approaching the actual ones for the blood at low, normal and moderately increased values of the volume velocity of the blood flow. The comparability of the results with the three most widely known and physically diverse methods of determining the minute volume of blood rules out a random nature for this conclusion.

Conclusions

1. The integral rheogram of the human body reflects the pulse redistribution of the stroke volume of the left ventricle in the arterial compression chamber as a whole during the cardiac cycle.

2. The proposed method of integral rheography of the body and the calculated formula make it possible to obtain values for the stroke and minute volumes of the blood in man, comparable with the acetylene method, the thermodilution method and the direct Fick method. The maximum value for random

errors guarantees the good resolution of the method, ensuring its suitability for measurement of the stroke volume of blood for each cardiac contraction, including those in arrhythmias.

3. Total harmlessness, simplicity, possibility of performance under any type of respiration, lack of an influence on measured parameters, possibility of prolonged usage and lack of a need to record additional processes of any kind make it possible to consider the method of integral rheography promising for extensive practical use, especially for relative evaluation of changes in the main hemodynamic parameters.

REFERENCES

1. Gismatulin, R. I., *Cor et vasa*, Vol. 4, p. 74, 1962.
2. Danilov, L. N., "Method of Thermodilution and Experience with its Use in the Surgical Clinic for Evaluating Changes in Hemodynamics," Author's abstract of his dissertation, Leningrad, 1970.
3. Zislin, B. D. and V. V. Suvorov, *Klin. Med.*, Vol. 5, p. 61, 1965.
4. Kedrov, A. A., "Electroplethysmography as a Functional Evaluation of Blood Circulation," Author's abstract of his dissertation, Leningrad, 1949.
5. Mazhbich, B. I., *Elektropletizmografiya Legkikh* [Electroplethysmography of the Lungs], Novosibirsk, "Nauka" Press, 1969.
6. Markel', A. L., *Klin. Med.*, Vol. 50, p. 50, 1965.
7. Moskalenko, Yu. Ye., *Problemy Kosmicheskoy Biologii* [Problems of Space Biology], Vol. 5, Leningrad, "Nauka" Press, 1967.
8. Tishchenko, M. I., "Biophysical and Metrological Bases of the Integral Methods of Determining the Stroke Volume of Blood in Man," Author's abstract of his dissertation, Moscow, 1971.
9. Tishchenko, M. I., *Tr. Inst. Normal'n. i Patalog. Fiziolog.* [Physiology and Pathology of Blood Circulation], Vol. 12, p. 69, Moscow, 1969.
10. Tishchenko, M. I., in the collection: *Metody Sbora i Analiza Informatsii v Fiziologii i Meditsine* [Methods of Collection and Analysis of Information in Physiology and Medicine], Vol. 22, Moscow, "Nauka" Press, 1971.
11. Tishchenko, M. I. and G. P. Zvonarev, *Tr. Inst. Normal'n. Patalog. Fiziolog* [Physiology and Pathology of Blood Circulation], Vol. 12, p. 72, Moscow, 1969.
12. Smirnov, A. D. and L. N. Danilov, in the collection: *Metody Sbora i Analiza Informatsii v Fiziologii i Meditsine* [Methods of Collection and Analysis of Information in Physiology and Medicine], Vol. 216, Moscow, "Nauka" Press, 1971.
13. Yakovlev, G. M., "Esophago-Thoracic Rheography and Its Use for Chronocardiometry in Healthy and Sick Persons With Mitrostenoses," Author's abstract of his dissertation, Leningrad, 1968.
14. Yarullin, Kh. Kh., *Klinicheskaya Reoentsefalografiya* [Clinical Rheoencephalography], Leningrad, "Meditsina" Press, 1967.
15. Bayley, R. and P. Berry, *Amer. Heart J.*, Vol. 63, p. 808, 1962.
16. Demange, J., Ch. Boutelier and J. Colin, *J. Physiol. (France)*, Vol. 60, p. 429, 1968.
17. Fejfar, Z. and M. Fejfarova, *Hamodynamische Veranderungen bei Kreislaufstorungen* [Hemodynamic Changes in Circulatory Disturbances], Berlin, 1961.
18. Geselowitz, D. B., *IEEE Transact. Bio-Med. Engineering*, BME-18, No. 1, p. 38, 1971.
19. Kubicek, W. G., J. N. Karnegis, R. P. Patterson, D. A. Witsoe and R. H. Mattson, "Development and Evaluation of an Impedance Cardiac Output System," *Aerospace Med.*, December, 1966.
20. Lepeschkin, E., *Das Elektrokardiogramm* [The Electrocardiogram], Leipzig 1957.
21. Nyboer, J., In: *Data Acquisition and Process. Biol. and Med.*, 133, Paris, Pergamon Press, 1962.

22. Sova, J., *Ann. N. J. Acad. Science*, Vol. 170, No. 2, p. 577, 1970.
23. Starr, I. and A. Noordergraaf, *Ballistocardiography in Cardiovascular Research. Physical Aspects of the Circulation in Health and Disease*, North-Holland, Amsterdam, 1967.
24. Warembourg, H., J. F. Merlen and B. Basin, *Mesure du Debit Cardiaque par la Rheographie par Impedance* [Measurement of Cardiac Debt By Impedance Rheography], Lille Med., (Special issue), p. 53, 1964.

Translated for the National Aeronautics and Space Administration under Contract NASw-2037 by Techtran Corporation, P. O. Box 729, Glen Burnie, Md. 21061.
Translator: William J. Grimes, M.I.L.